DOCUMENT RESUME

ED 216 877 SE 037 701

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TITLE Minicomputers in the Teaching Laboratory - An Example from Physics.
PUB DATE [82]
NOTE 7p.

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *College Science; *Computer Oriented Programs; Engineering Education; Higher Education; *Instrumentation; *Microcomputers; *Physics; Science Activities; Science Education; *Science Experiments; *Science Instruction
IDENTIFIERS Microprocessors

ABSTRACT

Microcomputers are commonly interfaced to external devices in scientific, industrial, and consumer settings for data acquisition and for control. The general problem under consideration is the task of taking measurements of some continuous phenomenon, transforming them into digital form, and storing the data in the microcomputer for later use. First, the physical variable to be measured must be changed to a voltage (or resistance) by means of some transducing device; for example, light intensity can be transduced to a voltage using a photocell. Then, too-large or too-small voltages need to be amplified. Next, the continuous voltage is converted to a digital representation in eight bits. Finally, the analog-digital converter is connected to the data address, and control buses of the microcomputer. Microcomputers such as Apple, TRS-80, Atari, Compucolor, and others, have a "game paddle" which is used to accomplish all of these steps while another method involves using a thermocouple. Once the system is ready, such experiments as those involving pendulums can be easily accomplished, a typical program recording the position of a swinging pendulum, displayed the motion on the monitor, and displaying graphs of variables examined during the experiment. Most students prefer using the computer as it swiftly and accurately performs the experiment's busywork. (Author/JN)

MINICOMPUTERS IN THE TEACHING LABORATORY -AN EXAMPLE FROM PHYSICS

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Introduction

Minicomputers or microprocessors are commonly interfaced to external devices in scientific, industrial, and consumer settings. They are used for data acquisition and for control. We think it is important for not only our science and engineering students but for everyone in our physics courses to begin to understand how computer interfacing can be used.

Using a minicomputer as a data acquisition device can remove the tedium of acquisition and analysis. The process is so much speeded up that the student-experimenter can devote more time and energy to the phenomenon itself. The TV monitor is a friendly environment which most students relate to easily. They are more likely to be comfortable and interested, especially if the computer program incorporates graphics.

The cost of an experiment can be minimal (excluding the purchase of the minicomputer). In fact, it may be cost effective in setting up new laboratories to use minicomputers and substantially fewer meters, oscilloscopes, timers, etc.

Interfacing

The general problem under consideration is the task of taking measurements of some continuous phenomenon, transforming them into digital form, and storing the data in the minicomputer. Later the stored data can be manipulated. This process can be easy, as will be shown, so the novice should not be deterred by the potential difficulties. Some measurements can be done with minimal electronics and many more difficult situations can be handled with commercially available components at reasonable cost.

First, the physical variable to be measured must be changed to a voltage (or resistance) by means of some "transducing" device. For instance, angular position can be transduced to a resistance using a potentiometer (pot.), or a temperature can be changed to a voltage using a thermocouple. Light intensity can be transduced to a voltage using a photocell.

Second, in the electronic "signal conditioning" phase, too-large or too-small voltages may need to be amplified. Additionally there may be a need to isolate the transducer or match impedences. The goal is to make the voltage variations compatable with the input requirements of the next stage.

The third step converts the continuous voltage (frequently 0 → 5v or -5 → 5v) to a digital representation in eight bits. (An analog-to-digital (A/D) converter could create more or fewer bits, but many microcomputers have an eight bit data bus so having more bits creates programming complexities while having fewer bits reduces precision.) Eight bits resolves a voltage swing of 0 → 5v into 256 steps of .0195v or 0.4% increments. This gives adequate precision for most applications.

Finally, the A/D converter is connected to the data bus, address bus, and control bus of the minicomputer. This step requires a lot of knowledge about the signal timing and organization of the minicomputer and A/D converter. Many users both new and experienced will wish to buy a commercial unit to short cut the complications.

Once the connections are made properly, the A/D converter can be viewed as several memory locations with specific addresses. Therefore the commands normally used in Basic to read from and write to memory

(PEEK and POKE) can be used to read and control the A/D converter. For some purposes programming in machine language is desirable and LDA and STA commands would be used.

A NIFTY TRICK AND FIRST EXAMPLE

If the preceeding explanation looks tedious and/or hopeless, take heart; there is a wonderful short cut. Many minicomputers (Apple, TRS-80, Atari, Compucolor, and others) have a "game paddle" which is used to accomplish all these steps. The Apple uses a 150 kilohm pot. in its game paddle. So any physical phenomenon that could be transduced into a 0 → 150 kilohm resistance change could be read using the Basic command PDL (O). For instance, a 150 kilohm thermistor could be used to measure temperature.

In our teaching laboratory we used the shaft of a 1 megohm pot. as the pivot of a pendulum. The 1 megohm pot. is wired to pin 1 and pin 6 of a 14 pin block. The game paddle block is removed and this block put in its place. The pendulum is now connected to paddle port zero and everything but very large swings will produce a 0 → 150 kilohm change in resistance. The angular position of the pendulum can be read and displayed using: PRINT PDL (O).

Our program measures time by using a BASIC loop. This method is the least accurate, but suitable for this case. For faster timing the accuracy of a machine language routine is desirable. For some applications an external clock that interrupts the computer would be needed.

A SECOND EXAMPLE - THE THERMOCOUPLE

This example is presented to show how the interfacing problem is more generally solved.

The transducer is a copper-constantan thermocouple with output of approximately 0.2mV/^{o}F. Over a temperature range of 32^{o} to 102^{o} F the voltage change is about 1.5 mV.

The signal conditioner used is a scientific amplifier (Analog Devices AD521). It is powered with a 9 V battery and the gain resistors are adjusted (gain = 2×10^3) so that the voltage output varies from 1 to 5V for temperature variation from 0^{o} to 125^{o} F. A voltage offset is required to do this. The scientific amplifier is connected to the thermocouple with the shortest possible leads to reduce pickup. The amplified signal can be carried on fairly long wires to the A/D converter.

The A/D converter used is an Interactive Structures Inc. AI02 which allows for sixteen $0 \rightarrow 5$V inputs.

The total cost of the above system is less than \$150.00. Each additional thermocouple up to sixteen total costs less than \$25.00. Even though this is more expensive than necessary, the hookups and programming considerations are minimal. Those that want to learn more and spend less can purchase a cheaper scientific amplifier and build their own A/D converter for approximately \$30.00. (See Hands On!, Winter 81-82, p. 14, TERC, 8 Eliot Street, Cambridge, MA 02138.)

THE PENDULUM EXPERIMENT IN THE TEACHING LABORATORY

For the motion of a pendulum, four quantities are easy to measure and correlate: mass (M) of the bob, length (L), amplitude (A), and period (T). For an ideal simple pendulum,

$$T \simeq 2\pi \sqrt{L/g}, \qquad (1)$$

(where g = acceleration due to gravity). T is independent of M and A, as long as A is not large.

Our program records the position of the swinging pendulum and displays the motion on the monitor. It then displays T and asks the student for the values of M and L. After several such runs the computer can display graphs of T vs. M, T vs. A, and T vs. L. These graphs clearly indicate the period's independence of mass or amplitude, but show a nonlinear dependence on length.

The computer can then plot lnT vs. lnL, and the result is a straight line. Although the scales on this graph are arbitrary and unlabelled, the program can calculate and display the slope, which is close to 0.5. Thus it is shown that

$$\ln T = \tfrac{1}{2}\ln L + \text{constant}, \qquad (2)$$

in agreement with the result obtained by taking the natural logarithm of eq. (1):

$$\ln T = \tfrac{1}{2}\ln L + \ln(2\pi/\sqrt{g}). \qquad (3)$$

Of the 54 students doing the lab, 49 said that they would prefer using the computer this way over the traditional method, using a stopwatch and a mass on the end of a string. When asked how well they enjoyed the experiment as compared to other physics experiments without a computer, 18 said "much more", 25 "somewhat more", 7 "no more", and 3 "somewhat less". Regarding their subjective impression of how much they learned, the response was not as favorable, although generally good: 6 "much more", 12 "somewhat more", 24 "the same", 8 "somewhat less", and 4 "much less".

The most frequently cited reasons for preferring the computer approach were: gaining firsthand experience with a microcomputer; and letting the computer swiftly and accurately perform the busywork of the

experiment. The most frequent complaints were: overcrowding (average of 4.5 students/machine at a time); and inadequate background information provided by the instructor. A small minority of students complained of a lack of sense of participation.

The students provided sensible suggestions for improving the lab; providing more background information ahead of time; reducing crowding; and making the program more foolproof and sophisticated, perhaps allowing greater student interaction with the machine (e.g., having the student measure the period, with the machine checking the result).

For those interested, our software is available on an unprotected DOS 3.3 disk for $10.00.